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AN OBJECTIVE COLOR MEASUREMENT SYSTEM PHASE IV INDUSTRY TRIAL

BY
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AUGUST 1990

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A preoperational industry trial of the Color Measurement System developed by the U.S. Army Natick Research, Development and Engineering Center (Natick) was conducted through the cooperation of the Defense Personnel Support Center (DPSC), the Defense Contract Administration Services and textile finishers from industry. Using computer-operated spectrophotometers, production samples of two Woodland camouflage printed, battle dress uniform fabrics were instrumentally evaluated for shade acceptability at textile finishers' facilities, DPSC and Natick. The samples were visually evaluated at DPSC. A unique color difference equation (Δ A) and acceptability (Chroma, Hue, Lightness) criteria developed by Natick were used to calculate the difference in color from the standard sample.

The data from all test sites were compiled at Natick for analysis of the agreement between the visual and instrumental and the interinstrumental pass/fail judgements. Statistical analysis of the data indicates good agreement for all tests sites. In most cases the agreement was better than 93 percent. Given the satisfactory results of this trial, the implementation of the objective method for determining shade acceptability into the Army's quality assurance program will proceed.

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PREFACE

The results reported here represent the fourth and final phase in the effort by the U.S. Army Natick Research, Development and Engineering Center (Natick) to develop an objective method for determining shade acceptability of textiles to be used in the procurement of textile items by the United States Army.

The study was accomplished through the cooperation of several federal agencies, and contractors from industry. Phase IV would not have been possible without the participation of three textile finishing corporations: Bradford Dyeing Association, Westerly, RI; Duro Textile Printers, Fall River, MA; and Delta Mills, Wallace, SC. The cooperation of these firms, which allowed the use of their facilities for the duration of the study, is greatly appreciated.

The Defense Personnel Support Center, Philadelphia (DPSC), PA and the Defense Contract Administration Services (DCAS), Regions Boston and Atlanta, contributed to the study by providing personnel to conduct testing both at DPSC and at the industry sites. The author appreciates the efforts of Ms. Carol Neri, Clothing and Textiles Branch, DPSC, and Ms. Patricia Dynan, formerly of DPSC, who conducted the visual and instrumental evaluations at that test site. Thanks are also due to the Quality Assurance Representatives (QAR) of DCAS regions Boston and Atlanta who participated in the trial. Mr. Richard Fiorey, Ms. Kathy Lemay, Ms. Audrey McCain, Ms. Marcia Weeden, and Mr. Joseph Wronkowski contributed to this study while assigned to the previously mentioned textile finishing companies.

The author would like to acknowledge Mr. Raymond Spring of the Advanced Systems Concepts Directorate (ASCD), Natick, who conducted the statistical analyses of the data. Grateful appreciation is also extended to Mrs. Robin St. Pere, Countersurveillance Section (COS), Natick, for her assistance throughout Phase IV and to Mrs. Lisa B. Hepfinger, also of COS, Natick, for sharing her knowledge and experience. Finally, the author would like to recognize and to thank Ms. Therese R. Commerford, Chief, COS and Mr. Maurice N. Larrivee, Chief, Countersurveillance and Process Technology Branch, Natick, for their continued support and guidance.

AN OBJECTIVE COLOR MEASUREMENT SYSTEM: PHASE IV INDUSTRY TRIAL

INTRODUCTION

BACKGROUND

To date, DPSC, the United States Army's procurement agency in Philadelphia, PA, has evaluated dyed or printed textile materials for conformance to shade acceptability specifications by the visual method traditionally used within the textile industry. The method has been standardized so that the government observer evaluates the procurement samples against a standard sample and physical tolerance limit samples under specified illumination and viewing conditions. However, conflicting interpretations of what constitutes an acceptable color difference sometime occur because the pass/fail acceptability judgment is ultimately the subjective opinion of the experienced observer. These conflicts are caused in part by differences among observers in the perception of, and response to, color stimuli.

While color is an important attribute for any garment, color is an especially important consideration for those garments used in military applications. In addition to the desire to achieve a compatible appearance for components of both the dress and combat uniforms for aesthetic purposes, the colors selected for the battledress garments serve a dual purpose in helping to protect the soldier. Multi-colored, disruptive camouflage patterns printed on the fabrics used in combat uniforms are designed to blend with terrain elements and to reduce the threat of detection. Large deviations from the terrain colors reduce the effectiveness of the countersurveillance properties and place the soldier at greater risk of detection by visual means during the day and by image intensification devices, which enhance visual capabilities, at night.

In the late 1970's Natick initiated the design and development of an objective method of evaluating shade acceptability as a means of improving the shade evaluation process and the quality of military end items. The method developed uses a spectrophotometer as an impartial observer, and provides quantitative colorimetric data by interfacing the instrument with a computer. A unique feature of the method is an objective color difference equation based on acceptability rather than perceptibility. Observer test data obtained for the coefficients in the acceptability equation are based on approximately 2400 experimental color decisions made by many observers. Therefore, both the contractor and the government can accept the pass/fail decisions made by a neutral observer, the color measurement system.

The system was designed as a network of instruments.[1] The network currently consists of two host systems, located at the government's

quality assurance and research laboratories, and satellite units located at several industry sites. Upon implementation, production samples normally submitted to DPSC for visual evaluation will be measured at the contractor's facilities and the acceptability data transmitted via telecommunications to DPSC for analysis, thus reducing the turn-around time for the evaluation process.

The early stages of this program focused on the design, development, procurement and testing of a prototype system. The objectives of Phases I and II were to design the system, and to develop an objective method for establishing shade tolerances with the use of a color difference (ΔA) equation based on acceptability.[2,3,4,5] In Phase III, the system of five units was assembled and the performances of the instrumentation tested as individual units and as a system.[6,7,8] Another achievement in Phase III was the derivation of numerical acceptability tolerances for three standard shades. These tolerances were used in a short operational trial which found the level of agreement in visual/instrumental and instrumental/instrumental acceptability decisions to be very good.[9]

PHASE IV: INDUSTRY TRIAL

The purpose of the final phase of this project was to determine whether the degree of correlation between visual and instrumental, and the interinstrumental acceptability judgments achieved in the laboratory could be reproduced in a production environment over an extended period of time, and to fine tune any problem areas prior to full implementation into the government's quality assurance program. The implementation is in progress and is expected to be completed in 1990.

PROCEDURE

Three finishers under contract to print woodland camouflage patterned fabrics accepted the opportunity to participate in the study. A satellite unit was installed at each facility. The Government Quality Assurance Representatives (QAR's), who were to conduct the testing at each site, had no previous experience with color measuring intrumentation. Therefore, they received instruction in system operation, measurement and basic maintenance procedures. The results of the study were used only for research purposes; procurement contracts were not affected by the instrumental pass/fail decisions.

The test was conducted in a round-robin format as shown in Figure 1. Two woodland camouflage patterned fabrics were studied. Site A tested samples of water repellant (Quarpel) treated 50/50 nylon/cotton (nyco) twill fabric used in the Chemical Protective Battledress Overgarment. Samples of 100 percent cotton, poplin ripstop fabric used in the Hot Weather Battledress Uniform (HWBDU) were measured at sites B and C. The QAR's were instructed to pull the test samples from the samples normally sent to DPSC for verification testing. According to standard sampling procedures, these samples are randomly chosen from within the production lot.[10]

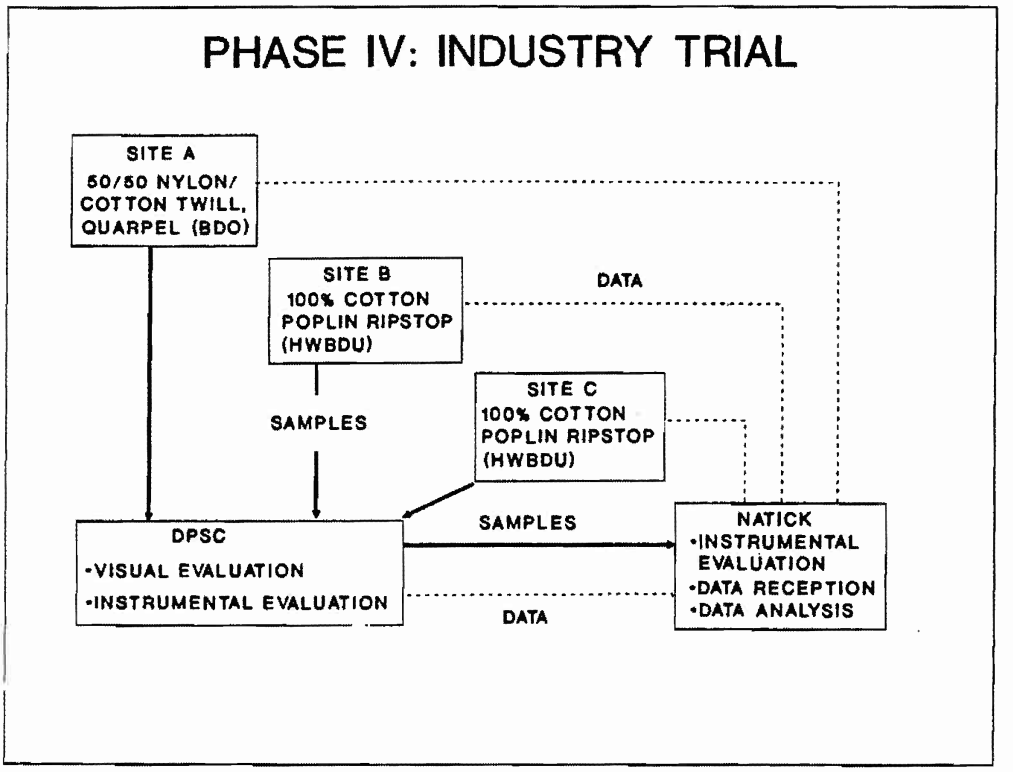


Figure 1

Round-Robin Format for Phase IV: Industry Preoperational Trial

The samples varied somewhat in size depending on the industry site of origin. For example, samples from one site were approximately 20 inches x 20 inches while samples from another were 12 inches x 20 inches. The QAR's selected and marked two measurement areas on the reverse side of every sample for each of the three shades studied: Light Green 354, Dark Green 355 and Brown 356. All measurements were made polychromatically, using a simulated D_{65} illumination source, inclusion of the specular component and large area of view mode (25 mm area viewed). The test participants were instructed to recalibrate the instrument if the measurement session exceeded two hours. A two-hour calibration cycle was used, rather than the four-hour cycle recommended by the instrument manufacturer as a control measure.

Each test site was supplied a piece of the standard roll with the measurement areas marked on the reverse side of the fabric. The standard

and production samples were backed at the port with a number of layers of the same fabric and color until infinite thickness was obtained. Four layers were used to back each shade of the cotton poplin ripstop fabric. Two layers were used to back each shade of the Quarpel-treated nyco twill fabric. To minimize the influence of surface texture on the instrumental readings, the diagonal weave lines of the nyco twill samples and the reinforcement ribs in the filling direction of the ripstop samples were oriented to the horizontal plane when presented to the sample port. The standard sample was measured each time a new lot was tested. Two measurements were taken in different areas for each shade and the values averaged. The colorimetric data were calculated for D_{65} and the CIE 1964 10 degree standard observer.[11]

After the samples were measured at the printing facility, they were sent to DPSC for visual evaluation of the shade and instrumental measurement. Natick performed the last round of instrumental measurements. The data from all the sites were transmitted via telecommunications to Natick for compilation and analyses.

The pass/fail acceptability data were calculated using the ΔA color difference equation developed in Phase II by Natick in conjunction with Allen and Yuhas of Lehigh University. Using the Allen/Yuhas method, acceptability is defined by an ellipsoid in CIELAB space, with the standard plotted at the center.[12] The three axes of the ellipsoid are defined by constants which correspond to the three directions in color space: hue, chroma and lightness. The length of each axis corresponds to the limit of acceptability in that direction. A fourth constant defines the orientation of the ellipsoid in the chromaticity plane.

ΔA represents an ellipsoid with its maximum limit set equal to 1.0. Therefore, a sample with a value of ΔA less than or equal to 1.0 would be acceptable. However, it is possible to scale ΔA upward or downward from 1.0 and still maintain the relative sizes of the chroma, hue and lightness axes, if the situation warrants such a correction.

The acceptability equation which defines the ellipsoid is as follows:

$$\Delta A = [g_{11}(\Delta a^*)^2 + 2g_{12}\, a^* b^* + g_{22}(\Delta b^*)^2 + g_{33}(\Delta L^*)^2]^{1/2}$$

The coefficients g_{11}, $2g_{12}$, g_{22} and g_{33} are given by the following equations:

$$\theta = \tan^{-1}(b^*_o/a^*_o)$$

$$g_{11} = (\cos^2\theta/c^2) + (\sin^2\theta/h^2)$$

$$2g_{12} = 2\sin\theta\cos\theta[(1/c^2) - (1/h^2)]^{1/2}$$

$$g_{22} = (\sin^2\theta/c^2) + (\cos^2\theta/h^2)$$

$$g_{33} = 1/v^2$$

Where: a_o^*, b_o^* = CIELAB a* and b* of the standard and the values for c, h and v are chroma, hue and lightness tolerances obtained from the observer panel data.

This equation, as well as, the numerical chroma, hue, lightness and maximum ΔA tolerances for each of the three shades studied were programmed into the computers. The acceptability criteria for this trial study are listed in Table 1. They are the same numerical chroma, hue and lightness tolerances developed for the nyco twill fabric in Phase III. These tolerances were used for both fabrics studied.

However, the overall ΔA tolerances, which represent the maximum allowable difference in color to the standard sample, were adjusted to reflect the broad visual tolerance range which exists for the Quarpel-treated nyco twill and the cotton poplin ripstop fabrics. The maximum ΔA values used as the pass/fail criteria are listed in Table 2. Figure 2 shows the acceptability ellipses for the colors on the cotton poplin ripstop fabric plotted in CIELAB color space.

Table 1. Numerical Tolerances for Three Colors of the Woodland Pattern

	Light Green 354	Dark Green 355	Brown 356
Chroma:	1.32	1.30	1.28
Hue:	1.16	1.11	0.74
Lightness:	2.26	2.20	1.88

Table 2. Maximum ΔA Values for Three Colors of the Woodland Pattern Printed on 100% Cotton Poplin Ripstop and Quarpel-treated Nyco Twill Fabrics

	Light Green 354	Dark Green 355	Brown 356
Cotton Poplin Ripstop:	1.90	2.25	2.55
Quarpel-treated Nyco Twill:	2.05	2.06	2.23

RESULTS AND DISCUSSION

The analysis was conducted on a total of approximately 1250 samples including 380 Quarpel-treated nyco twill and 870 cotton poplin ripstop samples. Another 200 cotton poplin ripstop samples were required to be kept on file at DPSC and were excluded from the sample population. Preliminary analyses indicated some erratic data which clearly resulted from a measurement error, such as measuring the wrong color. The exclusion of this data from the sample files for the site where the measurement errors occurred accounts for the slightly uneven distribution of the total number of tests conducted at each site, as listed in Tables 3 and 4.

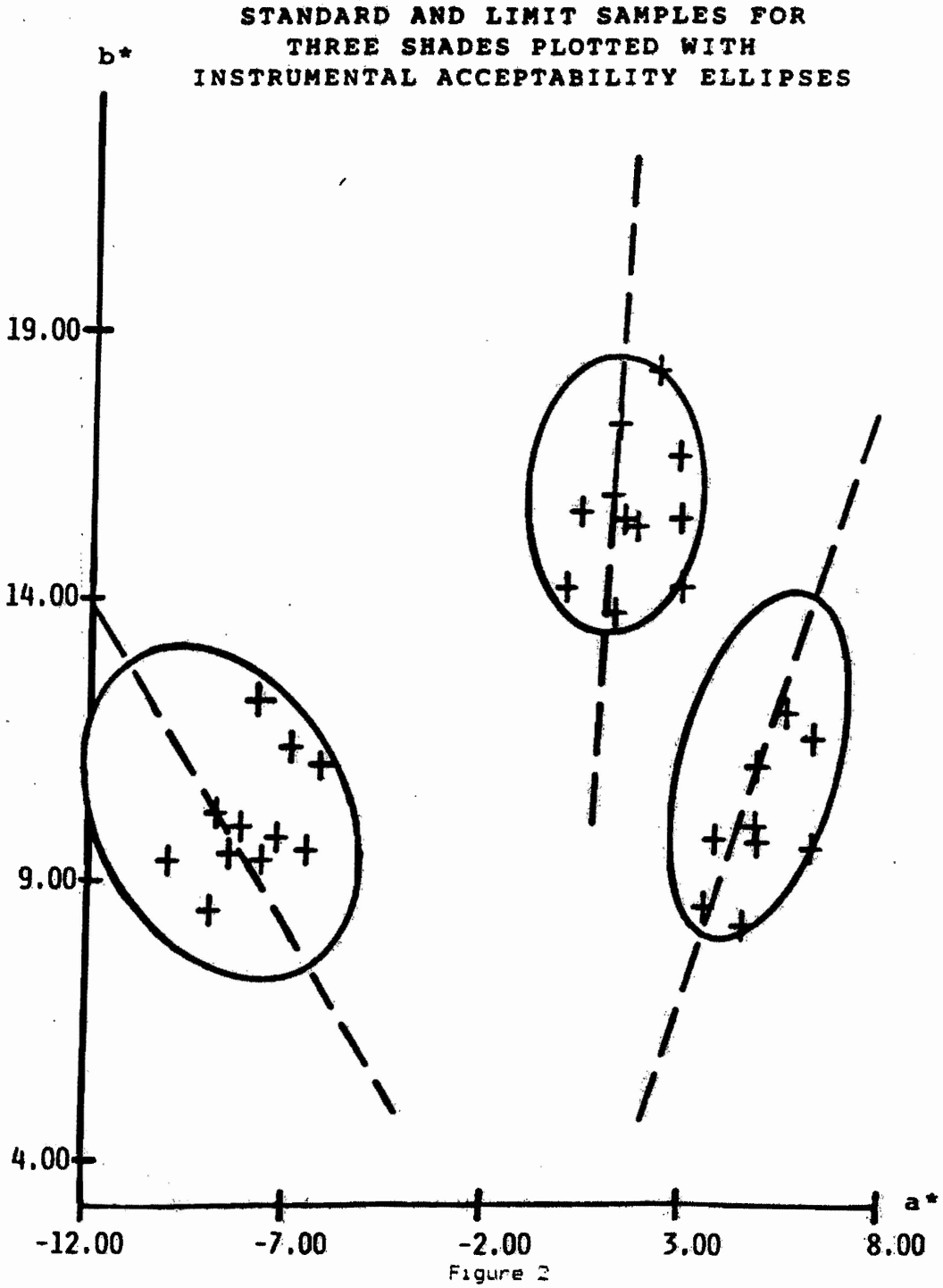


Figure 2

Standard and Limit Samples for Three Shades Plotted with Instrumental Acceptability Ellipses

All the samples included in this test were judged as "passes" when visually evaluated for acceptability at DPSC. When all the testing had been completed and the data compiled at Natick, it was analyzed to determine the level of agreement between the visual and instrumental judgments and then between the interinstrumental pass/fail judgments. The interinstrumental agreement was determined by comparing the pass/fail judgments for each of the satellite sites with those of Natick and DPSC. The results for both the visual/instrumental and interinstrumental analyses are found in Tables 3 and 4.

COMPARISON OF VISUAL AND INSTRUMENTAL ACCEPTABILITY DECISIONS

The level of agreement between the visual and instrumental judgments was high. The same pass/fail judgment was made by both the visual and instrumental evaluations for at least 93.2 percent of the samples at each test site, with the exception of the Light Green 354 samples tested at site C. There the level of agreement was 80.5 percent.

Table 3. Agreement of Visual/Instrumental Pass/Fail Judgments (%)

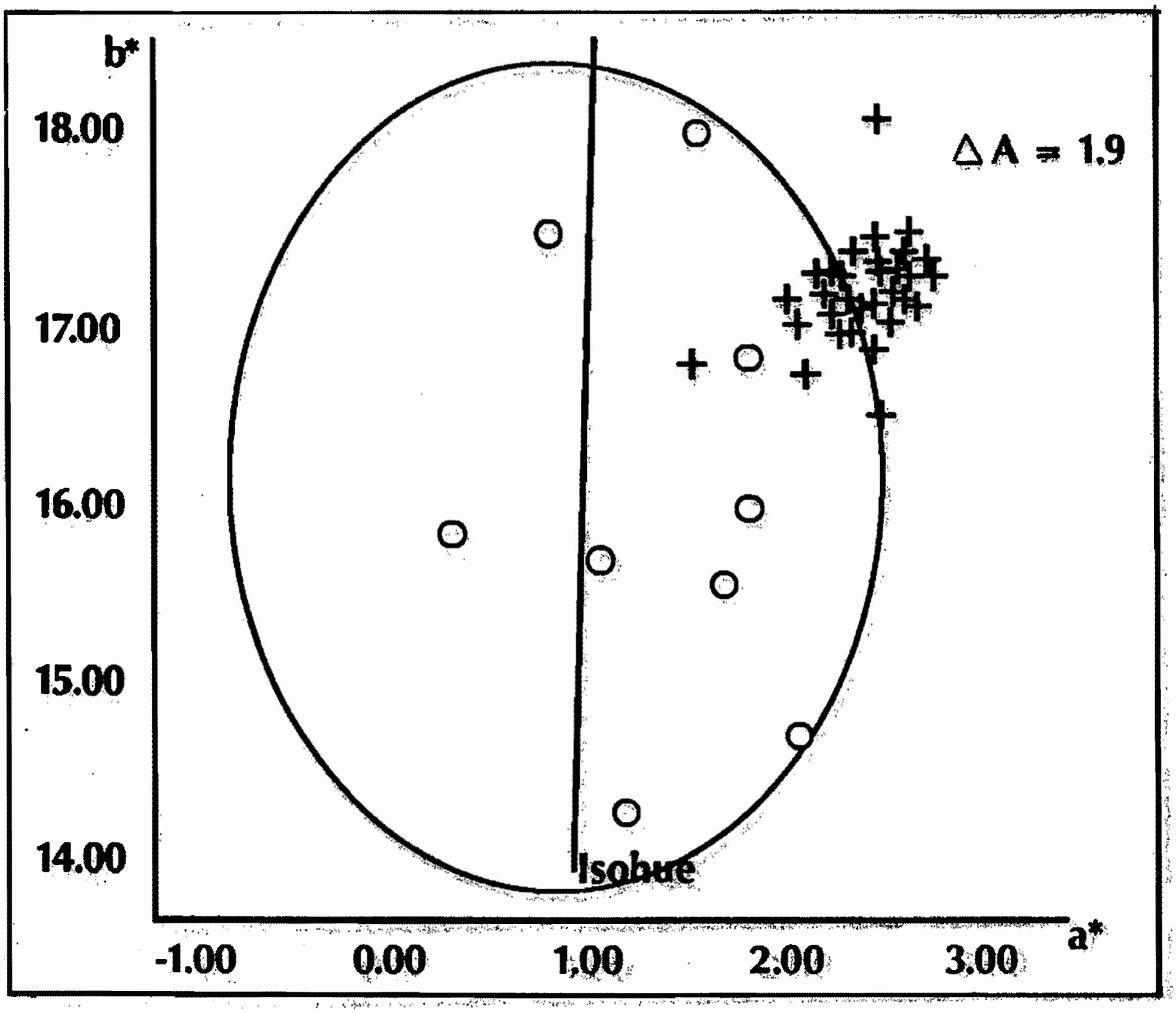
Woodland Pattern Camouflage Colors

	Lt. Green 354	Dk. Green 355	Brown 356
Natick	95.7 n=1210	97.9 n=1224	93.2 n=1221
DPSC	96.9 n=1182	97.6 n=1191	96.6 n=1213
A	96.3 n=383	96.1 n=383	95.5 n=379
B	99.8 n=656	98.7 n=638	100 n=632
C	80.5 n=226	94.5 n=221	94.8 n=234

n= Total number of tests

Examination of the numerical acceptability data for this group of samples revealed that a significant number (45) had acceptability factors slightly higher than the maximum numerical tolerance. The data for the Light Green samples were then plotted against the data for the visual limit samples and the numerical tolerances in CIELAB color space. The ellipse in Figure 3 shows that the Light Green samples from site C fall just beyond the maximum limit for both the visual and numerical tolerance limits. The procurement samples which fall inside the ellipse exceeded the maximum tolerance for lightness, the third dimension of color space, which cannot be plotted here.

While these samples were visually judged to be acceptable, the borderline of acceptability is an area where the visual observer is expected to experience some difficulty in making a judgment. This



○ = Visual Limit Samples

\+ = Samples Submitted by Contractor C

Figure 3

Plot of Limit Samples, Numerical Acceptability Ellipse and Procurement Samples of Light Green 354, 100% Cotton Poplin Ripstop Submitted by Site C in CIELAB Color Space.

difficulty is increased when the visual observer must judge a single color from within a complex field of four colors present in the camouflage material. The number of samples which exceeded the maximum acceptability tolerance had a greater influence on the level of agreement for site C, because the sample population for that site was much smaller than the total population of samples measured at Natick and DPSC.

COMPARISON OF INTERINSTRUMENTAL ACCEPTABILITY DECISIONS

The interinstrumental agreement was also quite good. Table 4 illustrates a high level of agreement ranging from 87.6 to 99.7 percent on instrumental pass/fail decisions for all test sites. The slightly lower levels of agreement for samples tested at site C may once again be a reflection of the small sample population for that site.

The interinstrumental data were also examined to determine what difference, if any, existed in the acceptability factors (ΔA) calculated for the sample data measured at each site. The results indicate that for a majority of the data there is a close relationship among the ΔA values produced in testing at the satellite sites and Natick and DPSC.

Table 4. Agreement of Interinstrumental Pass/Fail Judgments (%)

	Natick	DPSC	Natick/DPSC
A	91.4 n=1122	97.2 n=1077	89.5 n=1077
B	99.6 n=1902	99.5 n=1891	99.7 n=1894
C	90.8 n=609	90.5 n=592	87.6 n=587

n= Total number of tests

The graphs shown in Figures 4 to 30 represent the patterns found in the analysis and depict all possible pairwise combinations of ΔA values for each of the test sites, on each of the three colors tested. Each graph presents the total set of data points with the four possible judgments. The judgment was considered an agreement in the two cases where the paired test sites either both passed or both failed a test specimen. The judgments considered disagreements occurred in the two cases where one test site passed the test specimen and the other failed it. Each of these judgments is represented by a different symbol as described in the legends for the graphs. The best fit regression line for the total set of points is displayed along with the 95 percent confidence interval for individual points around this line. The band that is formed represents the area where there is a 95 percent confidence that additional points would occur if more samples were tested. It should be noted that the majority of data points illustrated represent samples which were judged as "passes" by both instruments.

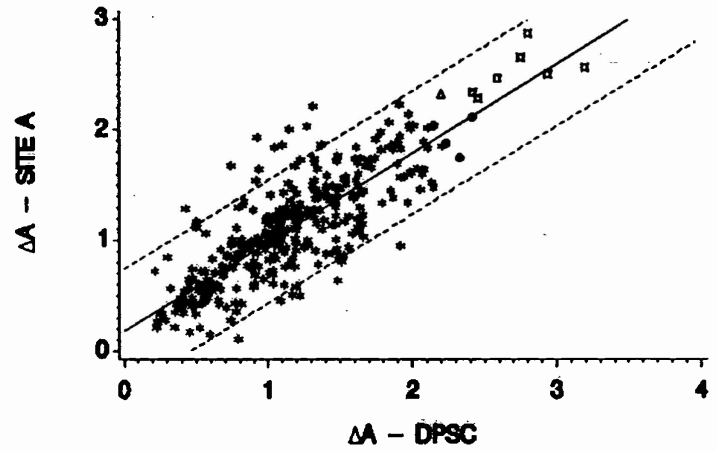


FIGURE 4
SITE A LIGHT GREEN 354
QUARPEL TREATED 50/50 NYCO TWILL
ΔA – SITE A VS. ΔA – DPSC

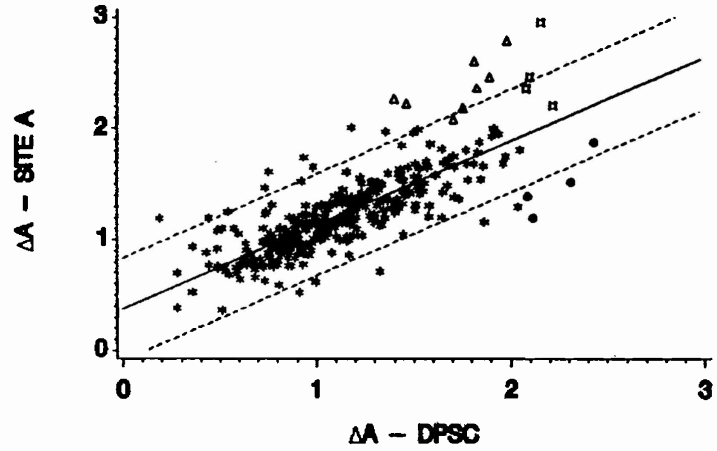


FIGURE 5
SITE A DARK GREEN 355
QUARPEL TREATED 50/50 NYCO TWILL
ΔA – SITE A VS. ΔA – DPSC

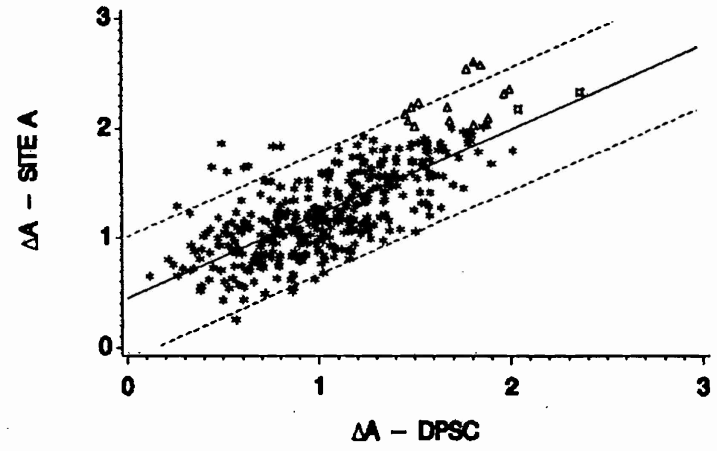


FIGURE 6
SITE A BROWN 356
QUARPEL TREATED 50/50 NYCO TWILL
ΔA – SITE A VS. ΔA – DPSC

LEGEND FOR SYMBOLS
FIGURES 4 – 6

FIGURES 4 – 6, LINEAR REGRESSION FIT AT 95 PERCENT CONFIDENCE LEVEL COMPARING ΔA NATICK VS. ΔA DPSC FOR THREE SHADES OF THE WOODLAND CAMOUFLAGE PATTERN, QUARPEL TREATED, 50/50 NYCO TWILL

* = BOTH DPSC AND SITE A PASS

¤ = BOTH DPSC AND SITE A FAIL

Δ = DPSC – PASS, SITE A – FAIL

• = DPSC – FAIL, SITE A – PASS

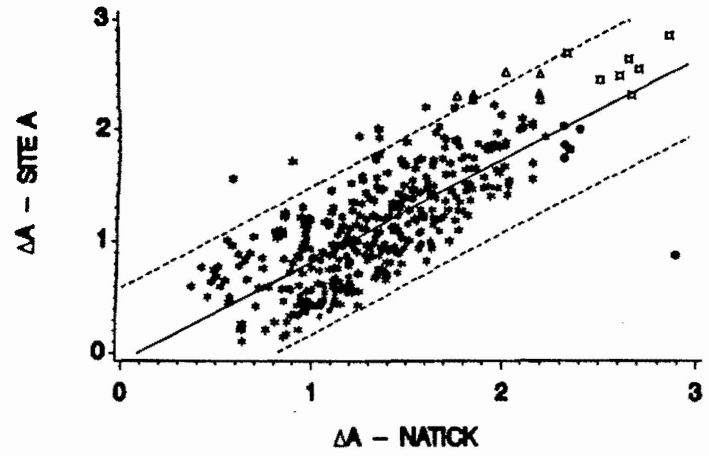


FIGURE 7
SITE A LIGHT GREEN 354
QUARPEL TREATED 50/50 NYCO TWILL
ΔA – SITE A VS. ΔA – NATICK

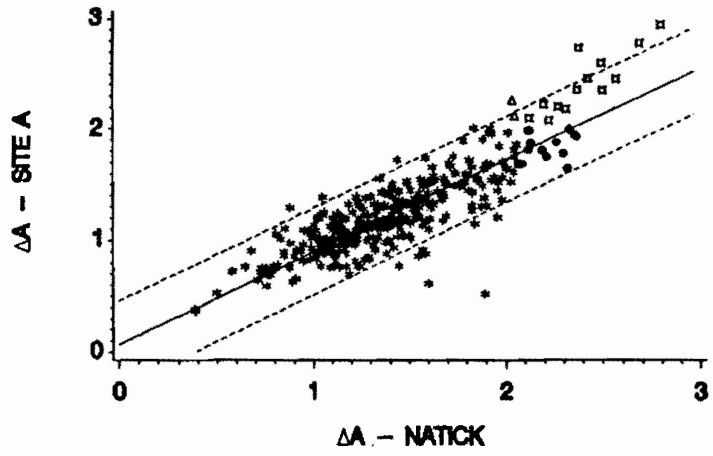


FIGURE 8
SITE A DARK GREEN 355
QUARPEL TREATED 50/50 NYCO TWILL
ΔA – SITE A VS. ΔA – NATICK

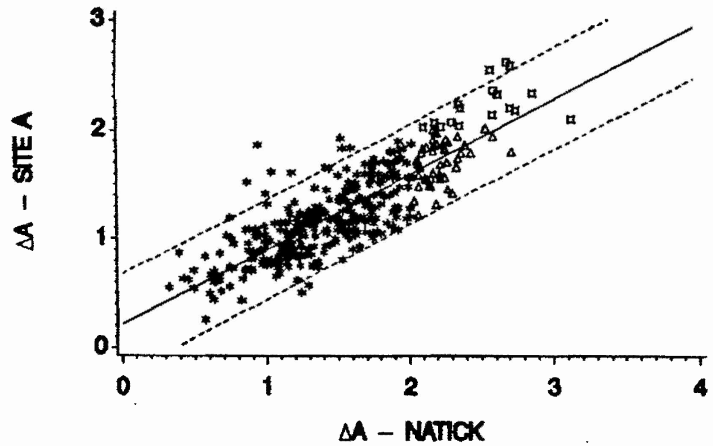


FIGURE 9
SITE A BROWN 356
QUARPEL TREATED 50/50 NYCO TWILL
ΔA – SITE A VS. ΔA – NATICK

LEGEND FOR SYMBOLS
FIGURES 7 – 9

FIGURES 7 – 9, LINEAR REGRESSION FIT AT 95 PERCENT CONFIDENCE LEVEL COMPARING ΔA NATICK VS. ΔA SITE A FOR THREE SHADES OF THE WOODLAND CAMOUFLAGE PATTERN, QUARPEL TREATED, 50/50 NYCO TWILL

• = BOTH NATICK AND SITE A PASS

¤ = BOTH NATICK AND SITE A FAIL

Δ = NATICK – PASS, SITE A – FAIL

▪ = NATICK – FAIL, SITE A – PASS

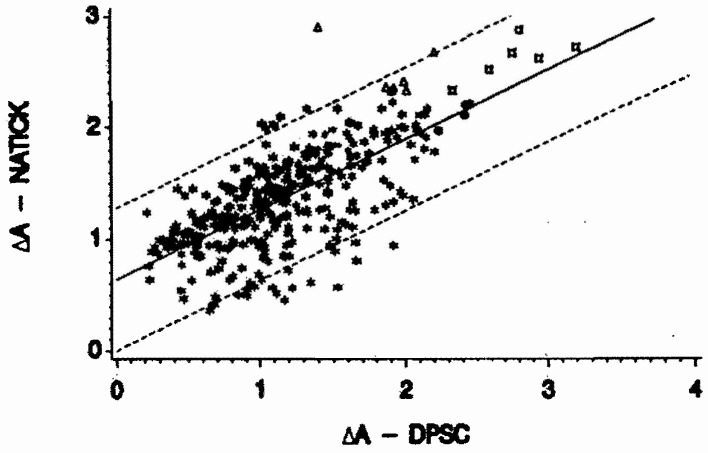


FIGURE 10
SITE A LIGHT GREEN 354
QUARPEL TREATED 50/50 NYCO TWILL
ΔA – NATICK VS. ΔA – DPSC

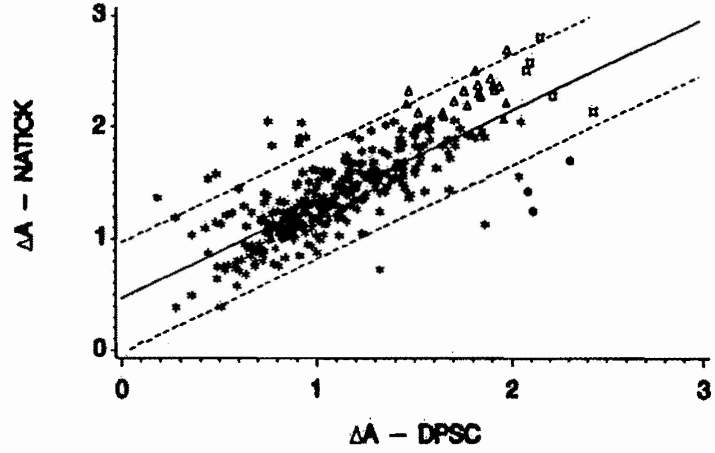


FIGURE 11
SITE A DARK GREEN 355
QUARPEL TREATED 50/50 NYCO TWILL
ΔA – NATICK VS. ΔA – DPSC

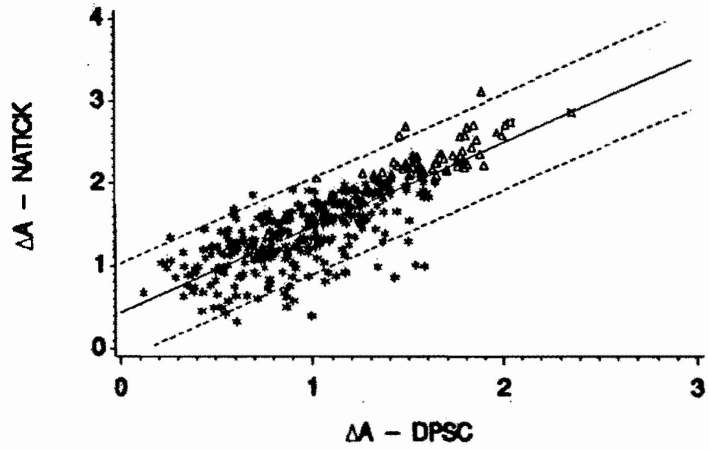


FIGURE 12
SITE A BROWN 356
QUARPEL TREATED 50/50 NYCO TWILL
ΔA – NATICK VS. ΔA – DPSC

LEGEND FOR SYMBOLS
FIGURES 10–12

FIGURES 10–12, LINEAR REGRESSION FIT AT 95 PERCENT CONFIDENCE LEVEL COMPARING ΔA NATICK VS. ΔA DPSC FOR THREE SHADES OF THE WOODLAND CAMOUFLAGE PATTERN, QUARPEL TREATED, 50/50 NYCO TWILL

* = BOTH DPSC AND NATICK PASS

¤ = BOTH DPSC AND NATICK FAIL

Δ = DPSC – PASS, NATICK – FAIL

• = DPSC – FAIL, NATICK – PASS

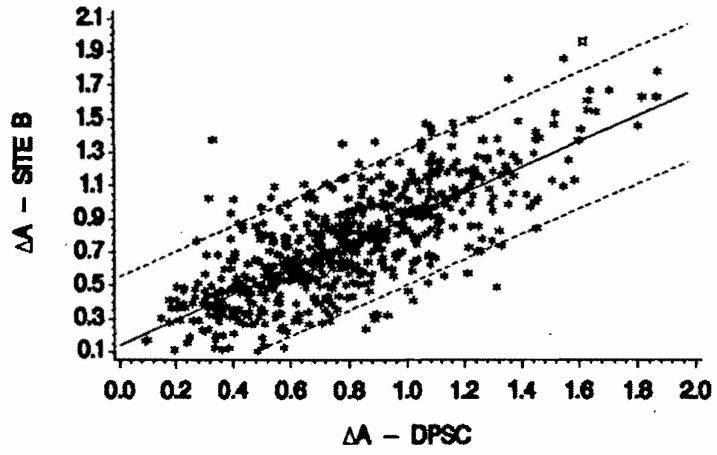


FIGURE 13
SITE B LIGHT GREEN 354
100% COTTON POPLIN RIPSTOP
ΔA – SITE B VS. ΔA – DPSC

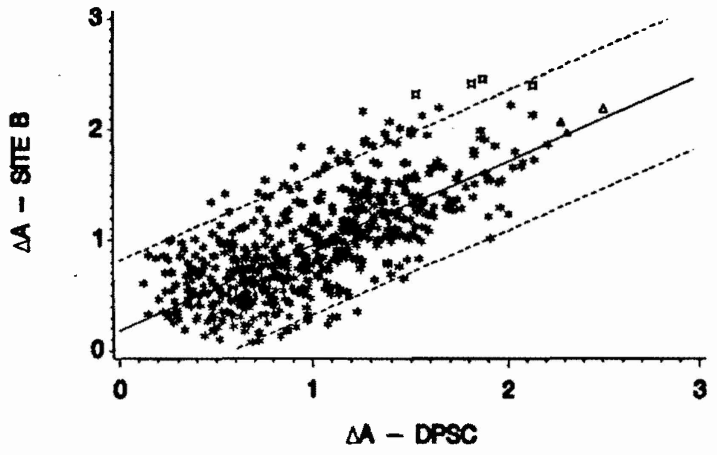


FIGURE 14
SITE B DARK GREEN 355
100% COTTON POPLIN RIPSTOP
ΔA – SITE B VS. ΔA – DPSC

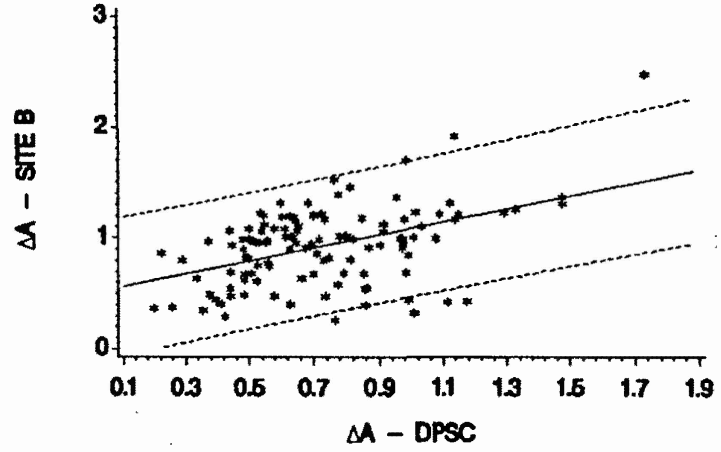


FIGURE 15
SITE B BROWN 356
100% COTTON POPLIN RIPSTOP
ΔA – SITE B VS. ΔA – DPSC

LEGEND FOR SYMBOLS
FIGURES 13 – 15

FIGURES 13 – 15, LINEAR REGRESSION FIT AT 95 PERCENT CONFIDENCE LEVEL COMPARING ΔA SITE B VS. ΔA DPSC FOR THREE SHADES OF THE WOODLAND CAMOUFLAGE PATTERN, 100% COTTON POPLIN RIPSTOP

* = BOTH DPSC AND SITE B PASS

¤ = BOTH DPSC AND SITE B FAIL

Δ = DPSC – PASS, SITE B – FAIL

· = DPSC – FAIL, SITE B – PASS

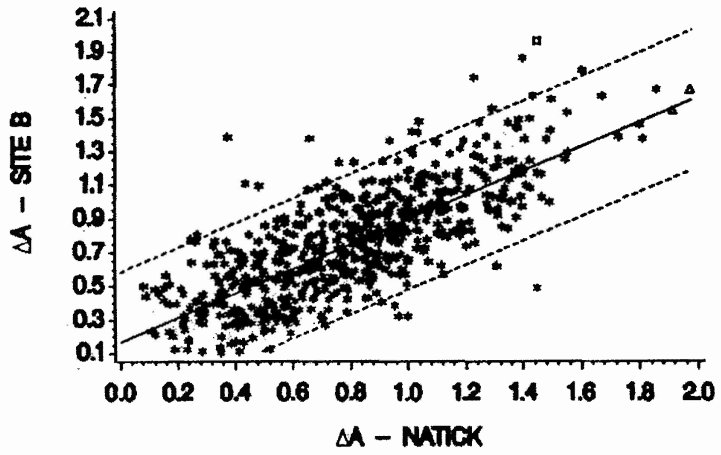


FIGURE 16
SITE B LIGHT GREEN 354
100% COTTON POPLIN RIPSTOP
ΔA – SITE B VS. ΔA – NATICK

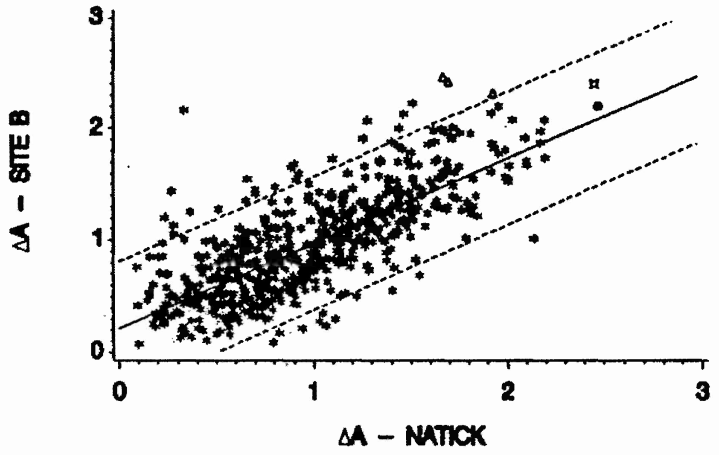


FIGURE 17
SITE B DARK GREEN 355
100% COTTON POPLIN RIPSTOP
ΔA – SITE B VS. ΔA – NATICK

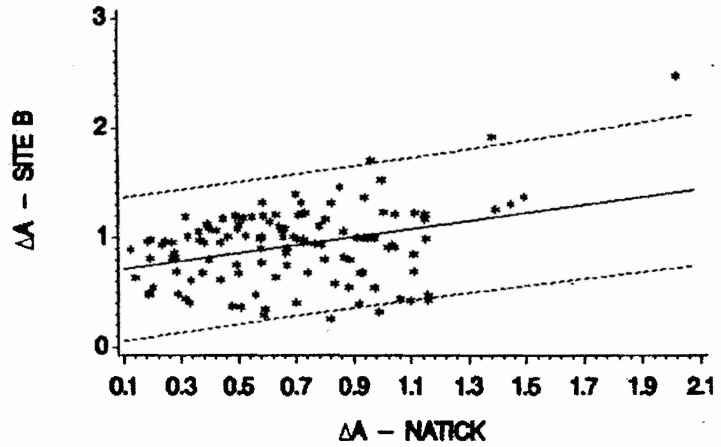


FIGURE 18
SITE B BROWN 356
100% COTTON POPLIN RIPSTOP
ΔA – SITE B VS. ΔA – NATICK

LEGEND FOR SYMBOLS
FIGURES 16 – 18

FIGURES 16 – 18, LINEAR REGRESSION FIT AT 95 PERCENT CONFIDENCE LEVEL COMPARING ΔA SITE B VS. ΔA NATICK FOR THREE SHADES OF THE WOODLAND CAMOUFLAGE PATTERN, 100% COTTON POPLIN RIPSTOP

* = BOTH NATICK AND SITE B PASS

¤ = BOTH NATICK AND SITE B FAIL

Δ = NATICK – PASS, SITE B – FAIL

• = NATICK – FAIL, SITE B – PASS

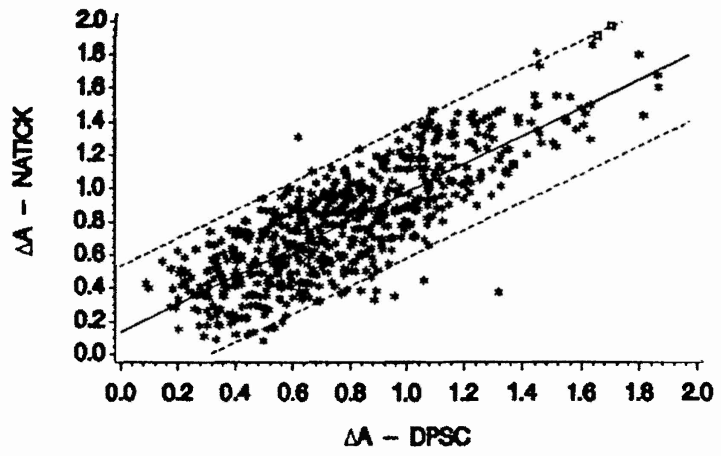


FIGURE 19
SITE B LIGHT GREEN 354
100% COTTON POPLIN RIPSTOP
ΔA – NATICK VS. ΔA – DPSC

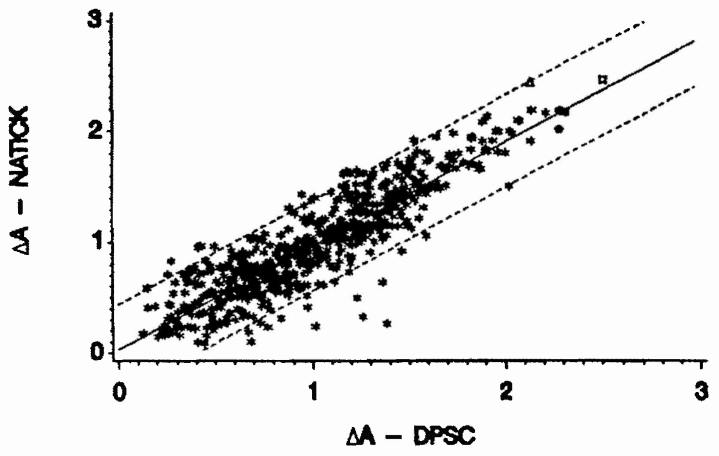


FIGURE 20
SITE B DARK GREEN 355
100% COTTON POPLIN RIPSTOP
ΔA – NATICK VS. ΔA – DPSC

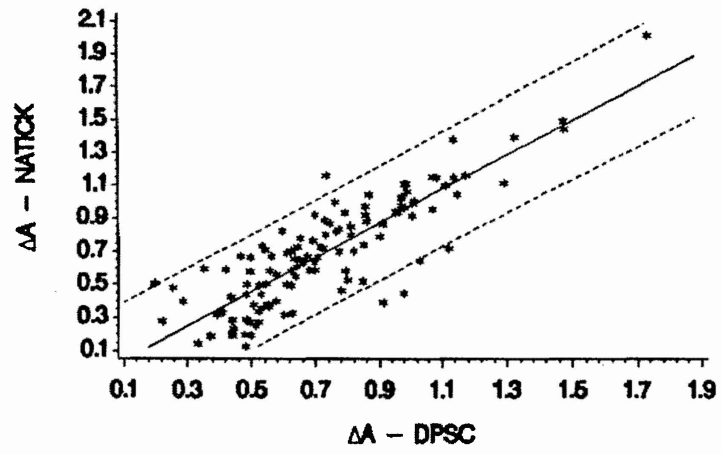


FIGURE 21
SITE B BROWN 356
100% COTTON POPLIN RIPSTOP
ΔA – NATICK VS. ΔA – DPSC

LEGEND FOR SYMBOLS
FIGURES 19 – 21

FIGURES 19 – 21, LINEAR REGRESSION FIT AT 95 PERCENT CONFIDENCE LEVEL COMPARING ΔA NATICK VS. ΔA DPSC FOR THREE SHADES OF THE WOODLAND CAMOUFLAGE PATTERN, 100% COTTON POPLIN RIPSTOP

* = BOTH DPSC AND NATICK PASS

¤ = BOTH DPSC AND NATICK FAIL

Δ = DPSC – PASS, NATICK – FAIL

• = DPSC – FAIL, NATICK – PASS

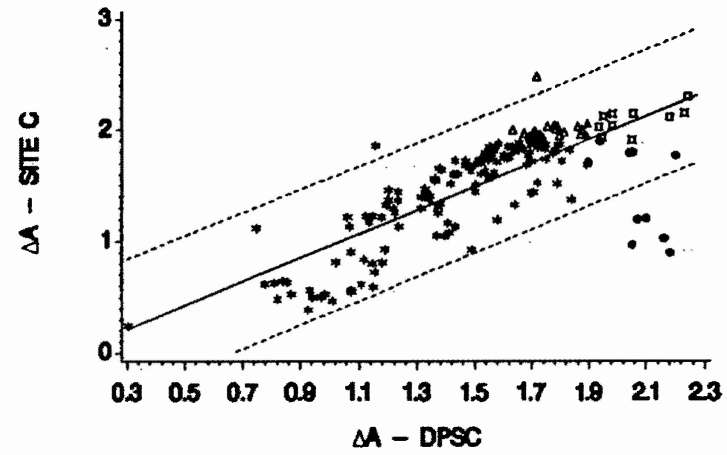


FIGURE 22
SITE C LIGHT GREEN 354
100% COTTON POPLIN RIPSTOP
ΔA – SITE C VS. ΔA – DPSC

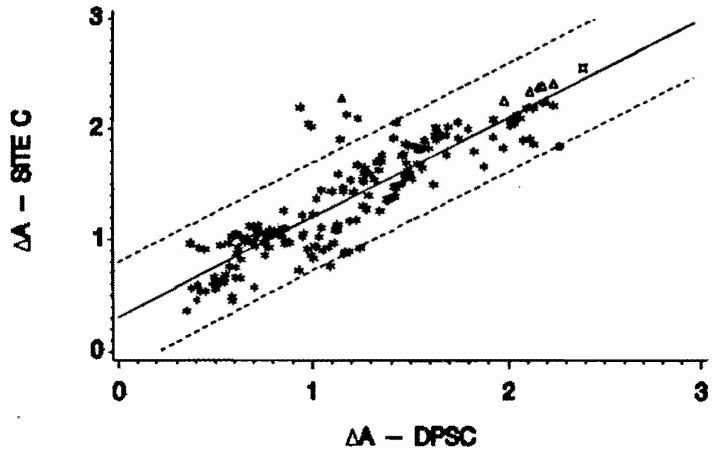


FIGURE 23
SITE C DARK GREEN 355
100% COTTON POPLIN RIPSTOP
ΔA – SITE C VS. ΔA – DPSC

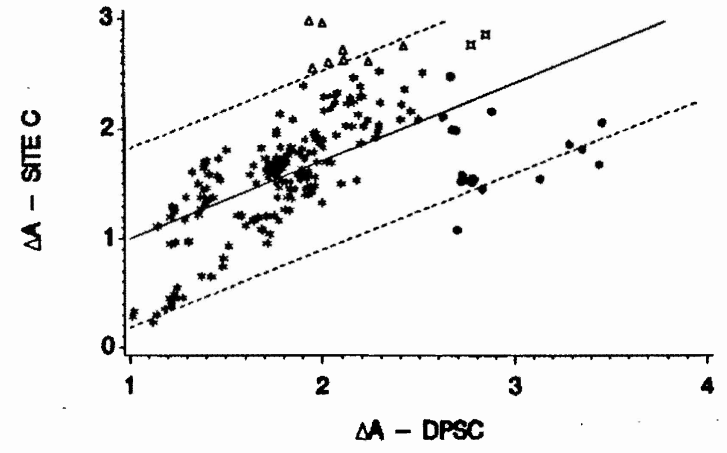


FIGURE 24
SITE C BROWN 356
100% COTTON POPLIN RIPSTOP
ΔA – SITE C VS. ΔA – DPSC

LEGEND FOR SYMBOLS
FIGURES 22 – 24

FIGURES 22 – 24, LINEAR REGRESSION FIT AT 95 PERCENT CONFIDENCE LEVEL COMPARING ΔA SITE C VS. ΔA DPSC FOR THREE SHADES OF THE WOODLAND CAMOUFLAGE PATTERN, 100% COTTON POPLIN RIPSTOP

* = BOTH DPSC AND SITE C PASS

¤ = BOTH DPSC AND SITE C FAIL

Δ = DPSC – PASS, SITE C – FAIL

• = DPSC – FAIL, SITE C – PASS

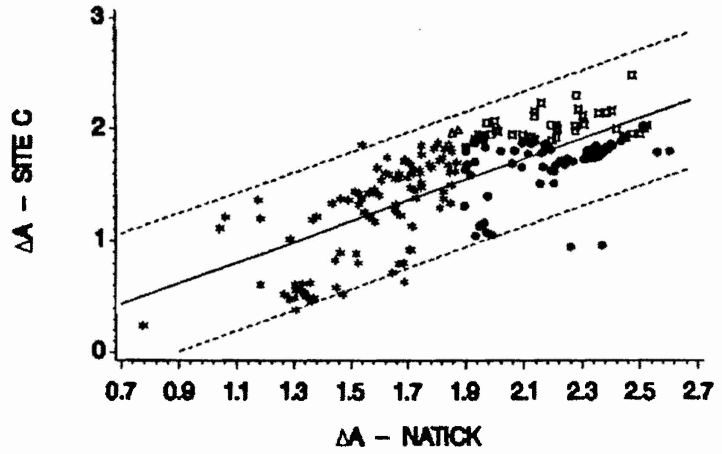


FIGURE 25
SITE C LIGHT GREEN 354
100% COTTON POPLIN RIPSTOP
ΔA – SITE C VS. ΔA – NATICK

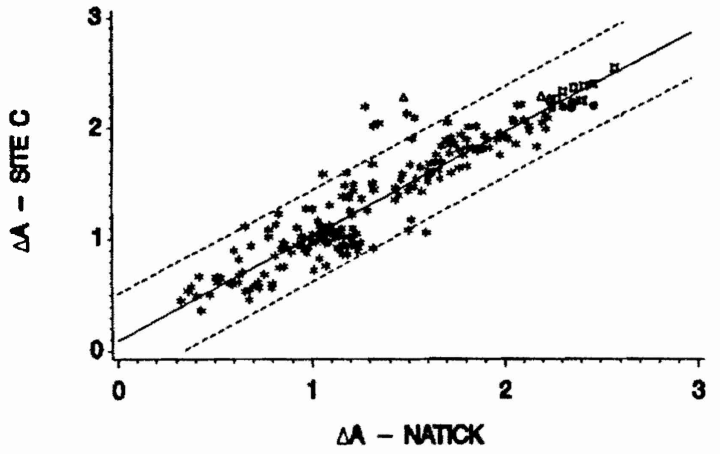


FIGURE 26
SITE C DARK GREEN 355
100% COTTON POPLIN RIPSTOP
ΔA – SITE C VS. ΔA – NATICK

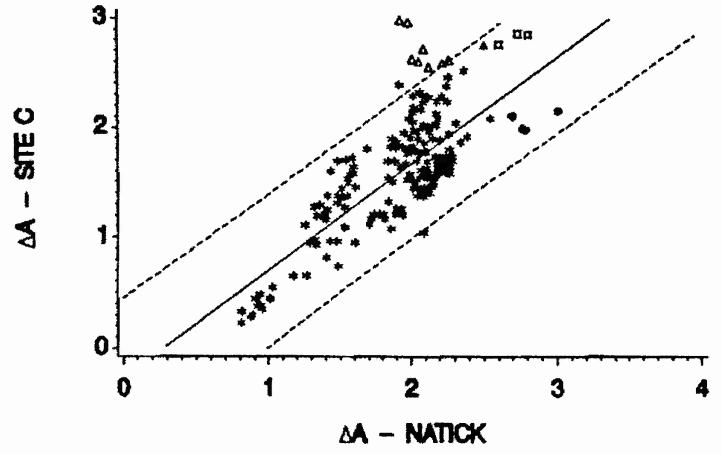


FIGURE 27
SITE C BROWN 356
100% COTTON POPLIN RIPSTOP
ΔA – SITE C VS. ΔA – NATICK

LEGEND FOR SYMBOLS
FIGURES 25 – 27

FIGURES 25 – 27, LINEAR REGRESSION FIT AT 95 PERCENT CONFIDENCE LEVEL COMPARING ΔA SITE C VS. ΔA NATICK FOR THREE SHADES OF THE WOODLAND CAMOUFLAGE PATTERN, 100% COTTON POPLIN RIPSTOP

* = BOTH NATICK AND SITE C PASS

¤ = BOTH NATICK AND SITE C FAIL

Δ = NATICK – PASS, SITE C – FAIL

• = NATICK – FAIL, SITE C – PASS

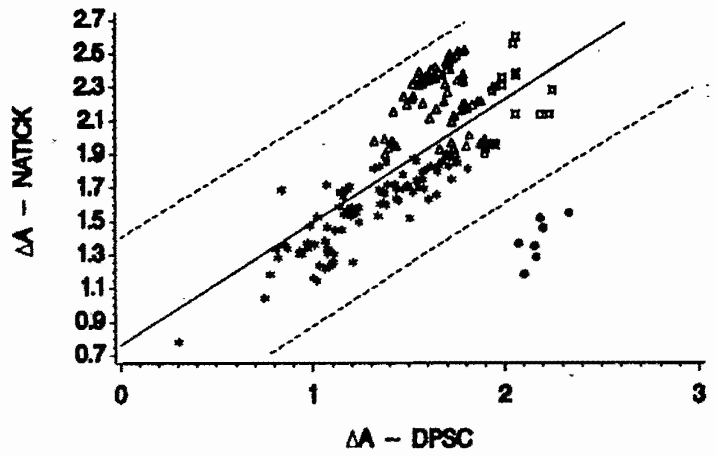


FIGURE 28
SITE C LIGHT GREEN 354
100% COTTON POPLIN RIPSTOP
ΔA – NATICK VS. ΔA – DPSC

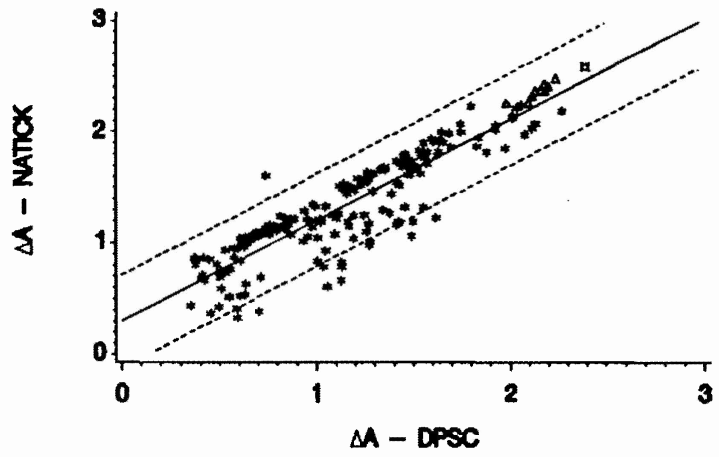


FIGURE 29
SITE C DARK GREEN 355
100% COTTON POPLIN RIPSTOP
ΔA – NATICK VS. ΔA – DPSC

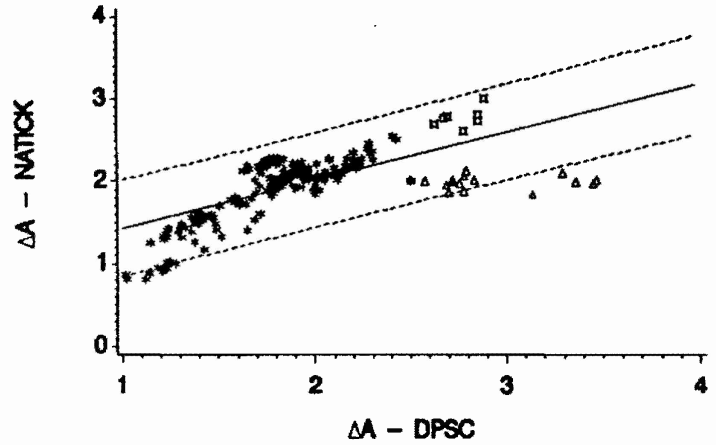


FIGURE 30
SITE C BROWN 356
100% COTTON POPLIN RIPSTOP
ΔA – NATICK VS. ΔA – DPSC

LEGEND FOR SYMBOLS
FIGURES 28 – 30

FIGURES 28 – 30, LINEAR REGRESSION FIT AT 95 PERCENT CONFIDENCE LEVEL COMPARING ΔA NATICK VS. ΔA DPSC FOR THREE SHADES OF THE WOODLAND CAMOUFLAGE PATTERN, 100% COTTON POPLIN RIPSTOP

* = BOTH DPSC AND NATICK PASS

¤ = BOTH DPSC AND NATICK FAIL

Δ = DPSC – PASS, NATICK – FAIL

• = DPSC – FAIL, NATICK – PASS

Although it is expected that different instruments will produce slightly different data, the L*, a* and b* data for both standard and sample data for each site were analyzed to determine if a clear cause for the differences could be found. The variables which could contribute to these differences include the instruments themselves and instrumental error; the number of operators with various levels of measurement experience conducting testing; different pieces of the standard roll measured at each site, and measurement procedure. No definite patterns appeared in the analysis but it did indicate more variability in the data for the three satellite sites than in the data for either DPSC or Natick. This would indicate that measurement procedure is the largest contributing factor to the differences in ΔA values between testing sites.

CONCLUSIONS AND RECOMMENDATIONS

The analysis demonstrates that the instruments performed well and the system works as intended. The implementation of the objective method for determining shade acceptability into the Army's quality assurance program will benefit the government and industry by reducing disputed acceptability decisions, reducing the turn-around time for the evaluation and improving the quality of military end items. However, it is important to remember that this method, or any other objective method for determining shade acceptability, is limited by the state of technology and the accuracy of the human element in the procedure.

Future developments in the optics and computer industries will bring greater speed and accuracy to commercially available instrumentation, which is presently very good. The human element in the procedure remains the important factor. Instrumentation must be maintained conscientiously, and careful measurement procedures are crucial. As Natick and DPSC work to transition this project from the development to the implementation stage, greater emphasis will be placed on training the operators in proper measurement procedures to maintain the degree of accuracy that has been produced in the laboratory, in the industrial environment.

This document reports research undertaken at the US Army Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-90/045 in the series of reports approved for publication.

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(10) Mil-Std-105D, Sampling Procedures and Tables for Inspection by Attributes, 29 April 1963.

(11) Commission International de l'Eclairage.

(12) CIELAB is the abbreviation for the uniform color space adopted by the CIE in 1976. It is an opponent-type color space based on the coordinates L*, a*, and b*.

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